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Mechanistic Studies of Pressure-Assisted Superplasticity of Structural Ceramics

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6. AUTHOR(S)

I-Wei Chen

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University of Michigan
2300 Hayward St.
Ann Arbor, MI 48109

8. PERFORMING ORGANIZATION REPORT NUMBER

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Air Force Office of Scientific Research (AFOSR/NE)
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Attn: Dr. Liselotte Schioler

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13. ABSTRACT (Maximum 200 words)

Microstructural and deformation studies have been conducted for superplastic zirconia and sialon ceramics. A methodology based on space charge concept is established for grain size control of zirconia ceramics. A direct correlation between grain boundary mobility and stress-strain curve is demonstrated. For silicon nitride ceramics, both single phase α' and β' sialons have been shown to be superplastic, and they exhibit a novel shear-thickening behavior which is interpreted by the breakdown of interparticle structural forces at high temperatures. Deformation experiments and numerical simulations of multiaxial superplastic forming are also reported.

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ANNUAL TECHNICAL REPORT

Objectives

Mechanistic understanding of microstructural and deformation aspects of fine grain superplasticity in structural ceramics, with special emphasis on the stress state effect.

Status of The Research Effort

The project was initiated on June 15 1987. During the twelve months between November 16, 1989 and November 15, 1990, the following accomplishments and progress were made:

1. Microstructural control of Superpalstic Zirconia Ceramics
   The grain size control of zirconia ceramics is now understood in terms of space charge concept. Essentially, the acceptor dopants of the highest effective charge and ionic radius are the most effective grain growth inhibitors. A positive correlation of the above concept, the grain growth kinetics, dynamic grain size stability, and the strain hardening rate in superplasticity has been established experimentally.

2. Rheological Behavior of Superplastic α' and β' Sialons

   Advanced powder processing has yielded fine grained α' and β' sialons which are superplastic at 1550°C. They have excellent formability and ductility. Their deformation behavior exhibits a novel transition from newtonian, linear viscous flow to non-linear, power-law type of flow, with a stress exponent less than unity. This is the first time that such flow behavior, termed shear softening, is observed in high temperature deformation. From the temperature and transient dependence of the transition stress, and from theoretical calculations of colloidal forces, we have tentatively concluded that a progressive collapse of the liquid film separating grains is the cause of the transition.

3. Superplastic Forming under Multiaxial Stress States
   Biaxial and uniaxial forming of zirconia and sialon ceramics have been performed to understand the effect of stress state on the formability of superplastic ceramics. Two modes of damage/failure have been observed, one containing diffuse cavitation and gradual rupture and the other containing sharp cracks and abrupt fracture. The morphology of both types of damage is strongly dependent on the stress state and the deformation mode, including the role of liquid phase creep. Numerical simulation of shell forming, which accounts for the strain rate dependence, has also been completed.

Publications

1. X. Wu and I-W. Chen, "Superplastic Bulging of a Yttria-Stabilized Tetragonal Zirconia," *Journal of American Ceramic Society*, **73** [3] 146-9 (1990).

2. C.M. Hwang and I-W. Chen, "Effect of a Liquid Phase on Superplasticity of 2m/o Y_2O_3-Stabilized Tetragonal Zirconia Polycrystals," *Journal of American Ceramic Society*, **73** [6] 1626-32 (1990).

3. I-W. Chen and L.A. Xue, "Development of Superplastic Structural Ceramics," *Journal of American Ceramic Society*, **73** [9] 2585-2609 (1990).

4. S.L. Hwang and I-W. Chen, "Grain Size Control of Tetragononal Zirconia Polycrystals Using the Space Charge Concept," *Journal of American Ceramic Society*, **73** [11] 3269-77(1990).

5. I-W. Chen, "Superplastic Ceramics," in Ceramic Powder III, Ceramic Transactions, V. 12, Proceedings of 3rd Internationl Symposium on the Science of Processing, Eds. E. Messing, S-I. Hirano, American Ceramic Society, p. 607-17 (1990).

6. I-W. Chen, "Superplastic Forming of Ceramic Composites," to be published, Composites, Eds. M. Sacks, *Proceedings of Second Ceramic Congress* (1990).

Personnel

I-Wei Chen, Professor of Materials Science and Engineering, PI.
Shyh-Lung Hwang, Ph.D. candidate
Xin Wu, Ph.D. candidate

Presentations

Invited Talks

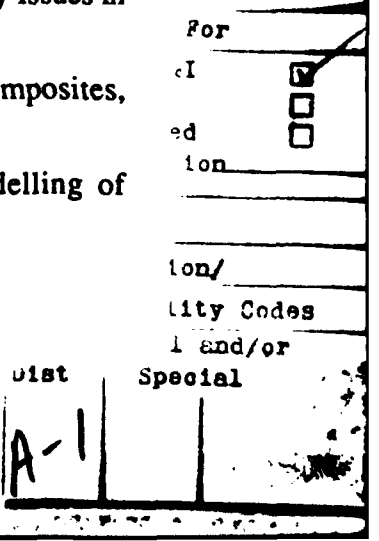
1. "Superplastic Forming of Fine-Grained Ceramics," at Department of Materials Science & Engineering, University of Washington, Seattle, WA, January 1990.

2. "Superplastic Forming of Fine-Grained Ceramics," at the Third International Conference on Ceramic Powder Processing Science, San Diego, CA, February, 1990.

3. "Superplastic Ceramics," at Albrecht-Rabenau Symposium on Contemporary Issues in Ceramic Science, Tegernsee, Germany, July 1990.

4. "Superplastic Forming of Ceramic Composites," at Symposium on Composites, Orlando, FL, November, 1990.

5. "Solute Drag and Grain Growth," at W.E. Heraeu's Seminar on Modelling of Sintering Processes, Bad Honnef, Germany, November, 1990.



Other Presentations (presenting author)*

1. "Superplastic Forming of Fine Grained Zirconia Ceramics and Composites," X. Wu* and I-W. Chen, at the 92nd Annual Meeting of the American Ceramic Society, Dallas, TX, April 22-26, 1990.

2. "Creep-Enhanced Dynamic Grain Growth of Superplastic Zirconia," S.L. Hwang* and I-W. Chen, at the 92nd Annual Meeting of the American Ceramic Society, Dallas, TX, April 22-26, 1990.

3. "Grain Growth Control in Nonstoichiometric Oxides—Space Charge and Boundary Mobility," I-W. Chen* and S.L. Hwang, at the 92nd Annual Meeting of the American Ceramic Society, Dallas, TX, April 22-26, 1990.

4. "Grain Growth in Fluorite-Structured Oxide Solid Solutions," S.L. Hwang,* S. Rutter and I-W. Chen, at the 92nd Annual Meeting of the American Ceramic Society, Dallas, TX, April 22-26, 1990.

Patent Disclosures

U.S. patent filed in February, 1990 by the University of Michigan on compositions and forming method of superplastic zirconia.